Integrating Forage, Wildlife, Water, and Fish Projections with Timber Projections at the Regional Level: A Case Study in Southern United States

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ABSTRACT / The impact of timber management and land-use change on forage production, turkey and deer abundance, red-cockaded woodpecker colonies, water yield, and trout abundance was projected as part of a policy study focusing on the southern United States. The multiresource modeling framework used in this study linked extant timber management and land-area policy models with newly developed models for forage, wildlife, fish, and water. Resource production was integrated through a commonly defined land base that could be geographically partitioned according to individual resource needs. Resources were responsive to changes in land use, particularly human-related, and timber management, particularly the harvest of older stands, and the conversion to planted pine.

Resource planning occurs at several administrative and geographic levels. The significance of a regional perspective has been recognized in the development of policies and programs for timber (Southern Forest Resource Analysis Committee 1969), and there is increased recognition that regional patterns are important in the management of all resources (Risser and others 1984, Urban and others 1987). Legal mandates require that planners examine the cumulative impacts of future land-management activities. Consequently, the cumulative effects of site-specific activities on the surrounding landscape must be addressed.

A significant problem in forest and rangeland planning is the estimation of multiple resource outputs under alternative management strategies across different environmental systems. Multiple resource production can be estimated by (1) a single model developed to quantify all resources of interest or (2) networks that link extant policy models with newly developed resource models (Shifley and others 1986, Kirkman and others 1986). Models for land area (Alig 1986) and timber supply and demand (Adams and Haynes 1980) have been used to analyze management implications for regional timber supplies. Thus, the second approach was used in this study on the effects of future timber management in southern United States. While mechanistic and statistical models have been developed to describe the production of other resources, e.g., forage (Van Dyne and others 1977) or wildlife (Verner and others 1986), the paucity of these models at the regional geographic scale required the development of models that could link explicitly with extant land area and timber models.

The objectives of this paper are (1) to describe the implementation of a conceptual multiresource framework (Joyce and others 1986) in a policy study on the future of timber in the southern United States; (2) to present projections of forage, wildlife, water, and fish under future timber-management and land-use changes across the southern United States; and (3) to critique this method of resource integration.

KEY WORDS: Multiresource; Timber inventory models; Habitat evaluation; Forage; Wildlife; Trout; Regional planning; Forest conversion; Regional modeling

Implementation of Multiresource Framework

The importance of timber production in the South's regional economy is evident in terms of its value. Forest products rank among the top three agricultural crops in each of the 12 southern states (USDA

1988). This regional economy has importance nationally as nearly 40% of the nation's commercial forest land is located in these states (USDA 1988). Commercial forest land refers to public and private forested land that is capable of producing at least 20 cubic feet of wood per acre annually and that has not been reserved for other uses.

In the early 1900s, concern about timber regeneration after harvests of the original forests prompted national and regional studies designed to develop policies to sustain the South's timber resource. Continued concern about forest regeneration is now meshed with concern about the consequences of increased competition for land among commercial forestry, agriculture, and urban development (Alig and others 1983). Other sectors of the economy have risen in importance, and the evolution of the South's timber resource will affect wildlife and fish habitat, grazing opportunities, and water quantity and quality. The most recent forest policy study (USDA 1988) provided the opportunity to apply the multiresource framework described by Joyce and others (1986).

The future impact of timber management and land use on the production of other resources was examined within the region bounded by Virginia on the northeast and Oklahoma and Texas to the west (Figure 1). This study required the integration of the extant models with models developed for forage (Joyce 1988), wildlife (Flather 1988, Flather and others 1989), water (Ursic 1987), and fish (Flebbe and others 1988).

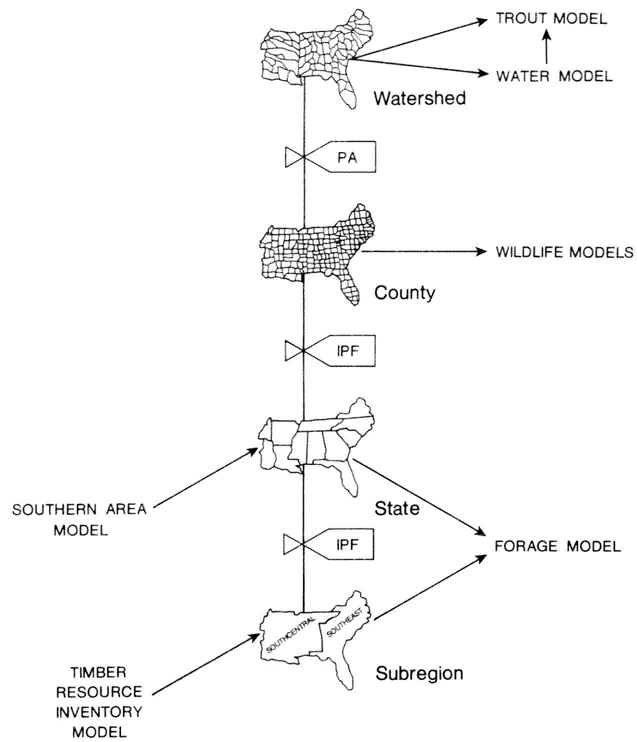

Figure 1. Land-base integration showing the different geographical scales at which projections for timber, land area, forage, wildlife, water, and trout were made (IPF = iterative proportional fitting, PA = proportional allocation).

Land-Base Integration for the Multiresource System

Our approach for integrating forage, wildlife, water, and fish projections was to link production through a commonly defined land base that could be geographically partitioned according to individual resource needs (Figure 1). Each resource within our multiresource system operated at a different geographic scale. Land-area shifts occurred among broad land-use and -cover categories at the state level. Timber growth was computed at the subregional level. Forage production was estimated at the timber-stand level. Wildlife, fish, and water—resources sensitive to land-use pattern—were projected at the county or watershed level.

The regional land base was compiled from the Forest Service (FS) Multiresource Inventory (McClure and others 1979), the Soil Conservation Service (SCS) Natural Resource Inventory (USDA 1987), and the Bureau of Census total area statistics. A set of land descriptors, common to these resource inventories and to the extant timber and land-area models, was developed (Table 1). These common descriptors formed the basis for any future aggregation or disaggregation of the land base. Coupled with forage, wildlife, water, and fish inventories from federal or state agencies, these land and resource data served as the basis from which models were developed and from which land-use and timber-management changes over time were distributed across the southern landscape.

The original plot-level data from the FS inventory were used to develop empirical models for timber growth (McClure and Knight 1984) and forest forage production (Joyce 1988). State-level data from the SCS inventory were used to develop pasture and range forage models (Joyce 1988).

For wildlife model development, a county-level land base was constructed from the three land-base inventories. Data for commercial forest land, productive reserved forest land, and unproductive forest land were taken from the FS inventory on the assumption that FS data were the most detailed and accurate for these land uses. Data for cropland, pasture, range, and human-related land (urban land, transportation corridors, strip mining, and farm structures) were taken

Table 1. Commonly defined timber and land-base descriptors significant in timber, forage, wildlife, water, and fish production processes at the regional level, and available from inventory measurements

Major land cover/use type
Forest land
Commercial forest land
Timber management type
Planted pine
Natural pine
Oak–pine
Upland hardwoods
Lowland hardwoods
Site class
High = greater than 100 ft^3/yr
Medium = 50–99 ft^3/yr
Poor = less than 49 ft^3/yr
Age class—10-yr age classes
Stocking class
High = greater than 100% stocked
Medium = 50–99% stocked
Low = less than 50% stocked
Merchantable volume (ft^3/year)
Productive reserve/unproductive
Cropland
Pasture/rangeland
Human-related land

from the SCS inventory, on the assumption that SCS data were the most detailed and accurate for these land uses. Iterative proportional fitting (Deming and Stephan 1940) was used to adjust FS and SCS land use and cover area estimates such that the sum across land uses and cover types was consistent with the total county area reported by the Bureau of Census. These adjusted county-level estimates deviated less than 1% from the original FS and SCS inventory estimates. Merging FS and SCS data resulted in a compositional description, at the county level, of the entire region. Information on size, shape, or distribution of individual land uses and cover types within counties was not available.

For fish and water development, land-cover and -use data within watersheds were required. The county-level land base was converted to a watershed-level land base. Land use and cover types were allocated to watersheds based on proportions of counties in each watershed (Flebbe and others 1988), assuming that the distribution of land use and cover types was uniform within a county.

Resource Models

The Southern Area Model, developed by Alig (1986), simultaneously projected state-level shifts among major land uses, cover types, and ownerships using economic and demographic variables. Shifts among timber-management types through succession or management activity were represented by a Markov probability matrix where nonstationary transition probabilities were associated with the conversion of a site from one type to another (Alig and Wyant 1986).

The Timber Resource Inventory Model (TRIM), developed by Tedder and others (1987), with the Timber Assessment Market Model (TAMM) (Adams and Haynes 1980) formed a modeling system that interacted to equilibrate timber supply and demand. The TAMM model projected future demand for standing timber in the forest and timber products. The TRIM model projected timber inventory (growing stock volume and area) by ownership, timber-management type, site class, and age categories within two subregions of the South (Figure 1). The broad ownership categories included public, farmer, nonindustrial private, and forest industry.

The forage model, developed by Joyce (1988), projected the production of herbaceous biomass within pasture, rangeland, and forest land as a function of environmental and land-management variables. On pasture and on range, forage production was modeled as a function of land area and a fixed production rate, similar to the regional vegetation models of Sharpe and others (1976). Range forage production rates were taken from the SCS range site descriptions (Joyce and others 1986). Pasture forage production rates were based on hay production within each state (USDA 1984).

Forage production on forested lands was modeled empirically as a function of timber-stand characteristics and environmental variables, similar to the state-level model of Joyce and Baker (1986) or site-specific models such as Clary (1979). Forest Service inventory data for timber and forage production were available for Tennessee, Alabama, and Louisiana. Timber-stand characteristics significantly associated with forage production varied by timber-management type and age class (Joyce 1988). As a percentage of the original standard deviation, the model standard errors were 10%–40% less variable than the original data.

The wildlife models, developed by Flather and others (1989), translated land base characteristics to wildlife habitat suitability through empirically generated relationships between the land-use and -cover patterns and the density classes or occurrence of selected wildlife species. Because the wildlife considered in these models are mobile—integrating land use and land cover over a landscape—a relatively large geographic area, the county, was chosen as the observational unit. Data of sufficient extent and detail existed for white-tailed deer (*Odocoileus virginianus*), wild turkey (*Meleagris gallopavo*), and red-cockaded woodpecker (*Picoides borealis*). Deer and turkey density class data obtained from the Southeastern Cooperative Wildlife Disease Study, University of Georgia, were used to assign each county to one of three density classes (low: 9 deer, 3 turkey per square mile; moderate: 19 deer, 7.5 turkey per square mile; high: 29 deer, 14 turkey per square mile). Within the primary range of the species, data on the presence or absence of active red-cockaded woodpecker nesting sites were obtained from the literature (Baker 1981, Carter and others 1983, James and others 1981, Wood and Wenner 1983), state fish and game agencies, Forest Service biologists, and state natural heritage programs.

Discriminant function analysis (Johnson and Wichern 1982) was used to relate land-use and forest-stand characteristics to the density or occurrence classes of the wildlife species. The average posterior probability of membership in each abundance class as predicted by the discriminant function analysis (DFA) model was multiplied by the midpoint density level for each class. These values were summed to get an estimate of expected density. Land base influences on red-cockaded woodpecker were assessed through changes in the number of counties predicted to retain active nesting sites. The habitat relationships established in the analysis were consistent with expert review and reported life history information. Resubstitution classification accuracies were 79%, 82%, and 80% for deer, turkey, and red-cockaded woodpecker, respectively. For each species, the number of counties correctly classified was significantly better than a random model ($P < 0.001$, kappa statistic) (Cohen 1968, Titus and others 1984).

The water model, described by Ursic (1987), was a combination of empirically generated relationships establishing the annual water yield across all watersheds and a matrix–response model quantifying the response of water yield to land-use changes within the mountain, Piedmont, and coastal plain physiographic regions. Streamflow data were obtained from US Geological Survey (USGS) gauging stations for 11 years (1973–1983). Precipitation data were obtained from annual climatological summaries. Regression models predicting water yield from land-use, timber-management, and precipitation data captured over 74% of the variability for watersheds of 100–700 square miles. These statistical models served to estimate the annual streamflow from watersheds for which data were not available.

Matrices of water yields and attendant changes from shifts of land-use and timber type–age classes were compiled using information from catchment experiments, state-of-the-art papers, personal knowledge (hydrologists from four physiographic provinces in the South), and other reference sources such as the climatological atlases. Each cell in the matrix (land-cover type × land-cover type) represented either the water yield for each cover type (the diagonal) or the net increase or decrease in yield when a type changes (off-diagonal). Changes in gross evapotranspiration, net interception of rainfall by different forest types, and distribution of pine species were incorporated in the estimated changes for water yield. Water yield was computed for each projection period by multiplying these matrices by a vector of land area by cover type.

The fish model, developed by Flebbe and others (1988), related watershed land base characteristics and annual water yield to fish abundance. The need to link directly to the land base and the regional scope of the model required a geographic unit for the fish model larger than the traditional stream habitat modeling framework (e.g., Binns and Eiserman 1979). The linkage to the water model required that the geographic unit for both models be the same. Therefore, the watershed was selected as the geographic unit for the fish model.

Only the cold-water fishery of the North Carolina and Virginia Appalachian area had been inventoried in sufficient detail to support a regional model (data of Bonner 1983, Neal 1980). Fish species were brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Salmo gairdneri*). Trout density (trout per acre of trout stream) for each watershed was determined by aggregating density estimates across all three species for all trout streams sampled in the watershed. To minimize errors that might result from assumptions about efficiency of sampling methods and the area of stream sampled, watersheds were assigned to low (50 trout/acre), moderate (130 trout/acre), and high (>363 trout/acre) density classes.

Discriminant function analysis (DFA) was used to relate trout density class to the land use and cover in watersheds and the mean annual water yield. Density classes predicted by the DFA model were converted to trout density estimates by calculating the weighted average density over all watersheds. Densities assigned to each class were weighted by the posterior probability of membership in each class for all watersheds. The classification rule generated by DFA correctly reclassified 78% of the watersheds containing trout streams.

Baseline Scenario and Alternative Futures

Baseline assumptions concerning population growth, economic growth, and timber management were developed for 1985–2030 (USDA 1988). Population was projected to increase, but at rates that declined from a 1% annual increase in the mid-1980s to 0.3% by 2030. Per capita disposable income was projected to be 2.3 times the 1985 value in 2030. Institutional and technological changes were assumed to affect the demand for timber products in the future as in the past. Timber management on pine plantations was assumed to intensify, resulting in a 10% increase in yields on pine plantations established with genetically improved stock. The minimum harvest age for pine stands was assumed to vary from 20 to 25 years for the southeastern and southwestern areas in the study area, respectively. The minimum harvest age for hardwoods was assumed to vary from 35 to 50 years, as a function of site class. Harvest age for public lands was set between 35 and 55 years for natural pine and oak–pine and at 60 years for hardwoods.

Using these baseline assumptions, projections for land use and timber inventory were made at the state or subregion level, respectively (Figure 1). Land area and timber volume were input directly to the forage model. The state and subregional projections of land use and timber inventory were distributed across the county-level land base in the following manner. The original county-level distribution of land use and cover was taken as the initial spatial pattern for the region. Projected land-base changes were distributed by adjusting land use and cover area at the county level through the iterative proportional fitting methodology in a stepwise fashion. Subregional estimates were adjusted to the state level, which were subsequently adjusted to the county level. As land-use changes occurred, and as the timber stands were harvested and replanted, the spatial distribution changed accordingly. This county-level land base was used as input to the wildlife models. The county-level land base was converted to the watershed-level land base and water yield was projected. Finally, the trout model received the water projections and land-cover changes from the watershed-level land base, and trout densities were projected for the cold-water fisheries region of the South.

In addition to the baseline condition, certain assumptions were modified to generate two alternative future scenarios. In the first scenario, an additional 11 million acres of forest land were converted to cropland gradually over the projection period. Cropland use increased by 16 million acres over the baseline. Concern over the measured declines in the radial growth of southern pines resulted in a second scenario that examined the consequences of a 25% reduction in the net annual growth on pine plantations, natural pine, and oak–pine stands. Causes for the measured decline have not been determined but could include changes in stand density and age, drought, the exhaustion of residual fertilizers in fields that regenerated to pine, increased hardwood competition, and atmospheric deposition. The assumed decline is in concert with the measured declines of 20%–30% over the past ten years in the South (Sheffield and others 1985). All other assumptions of the baseline scenario were held in these alternative futures.

Results

Baseline Scenario

Under the baseline scenario, land-area shifts are dominated by a 3% reduction of forest land and a 50% increase of human-related land (Table 2). Total pasture and range area declines over the projection period by 14% of the base year value. Area in planted pine increases substantially from 6% of the southern landscape to nearly 15%, representing a conversion of nearly 30 million acres in 45 years. This conversion involves primarily natural pine acres; however, upland hardwoods and oak–pine also are replaced with pine plantations. The older hardwood stands decrease substantially, while younger stands increase from 9.7% of the southern landscape to nearly 13%.

These changes in land area and timber management affect forage, wildlife, water, and trout differently (Figure 2). The decrease in pasture and range forage reflects the decrease in pasture and rangeland acres that dominate forage production in the South. The increase in forest forage does not compensate for the decline in pasture and range forage, and total herbage decreases over the projection period. Forest herbage production is greatest in the younger age stands and in pine types. Increases in forage follow the shift of forest land acres into the younger age classes as the older stands are harvested and regenerated. Plantations with a management emphasis on reduction of brush increases forage production also.

The wildlife responses to the baseline scenario vary by species because of differences in natural history and level of habitat specialization. White-tailed deer, having more generalized habitat requirements, have the least specific response to changes in any single land cover. Average deer density declines over the projection period (Figure 2) in response to an overall loss of forested habitat acres, specifically the loss of upland hardwoods and the conversion of natural pine and oak–pine stands to planted pine. Significantly increased area in human-related land uses also results in a direct loss of habitat and is associated with increased levels of human disturbance.

Table 2. Land area and timber management type changes resulting from baseline scenario, expressed as a percentage of total land area in the South[a]

Land use and cover	Year 1985	1990	2000	2010	2020	2030
Cropland	16.7	16.8	16.9	16.7	16.9	17.0
Pasture/range	15.6	15.3	14.8	14.2	13.8	13.4
Human-related	7.3	7.9	8.9	10.4	10.4	11.0
Forest land	56.2	55.9	55.3	54.6	54.7	54.4
Natural pine	12.7	11.8	9.3	8.0	7.6	7.4
Planted pine	6.4	8.1	11.6	13.3	14.3	14.8
Oak–pine	8.3	7.7	7.1	6.8	6.7	6.6
Upland hardwood	19.5	19.0	18.3	17.7	17.6	17.8
Lowland hardwood	9.4	9.3	9.0	8.7	8.5	8.3

[a]Excluding other lands (barren, beaches, mud flats, bare exposed rock) which remain constant over projection period.

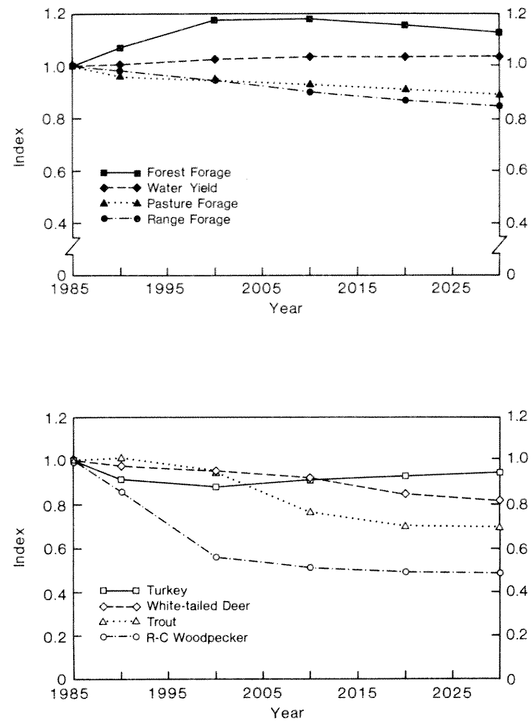

Figure 2. Multiresource response in the baseline scenario. Index is proportional change from 1985.

Wild turkey are more specific in their habitat requirements than deer, and the projected response is closely tied to the hardwood component of the forest land base. Following an initial decline in average density (Figure 2), the turkey population recovers in response to increased area in young and old hardwood management types.

The red-cockaded woodpecker is the most specialized in its habitat requirements. This species' dependence on mature pine stands results in a close tracking between presence of active nesting sites and acres in older natural pine stands. The rapid decline in the number of counties supporting active nesting sites is tied to the conversion of older natural pine stands to planted pine on private ownerships. The asymptotic decline is the result of counties with a relative high proportion of public ownership, in particular, national forest land, retaining active colony sites. Public ownerships do not harvest all pine acres at the 20-year rotation age and, thus, retain older age classes of pine required for suitable nesting habitat.

Water yields increase slightly during the projection period. This increase is primarily the result of increased human-related land. Across the South, temporal patterns of change vary. In the southeastern subregion, essentially all of the changes occur between 1985 and 2010, while in the south-central subregion, the changes begin about 1990 and gradually increase to 2030. These changes follow the shifts in human-related land in each subregion.

Land base trends within the mountain areas that support trout differ slightly from the South-wide trends described above. Cropland area remains nearly constant, human-related land use increases less than in the South as a whole, conversion to pine plantations in the mountains is minimal, and acres in older age classes of upland hardwoods decline significantly throughout the projection period. Trout density (Figure 2) declines largely in response to cutting of old hardwood acres and the general increase in human-related land use over the projection period. When old hardwood acreages are cut, shading declines and water temperature increases, reducing habitat for trout. At the same time, human-related land use is increasing at the expense of high-quality trout habitat.

Alternative Futures

In the first scenario, the loss of forest land does not have a large impact on the timber economy, primarily because the conversion to cropland occurs slowly over the projection period (USDA 1988). Timber inventory in 2030 is only 4% below the baseline projection. However, this reduction in area does have significant impacts on forage, which declines across the South from the baseline levels (Table 3). Because the spatial distribution of cropland varies across the South, so does the response of deer. In areas where increased cropland contributes to increased fragmentation of forest land, this change results in more favorable habitat conditions and higher deer densities. In other parts of the southern forest land already fragmented by cropland,

Table 3. Simulated effects of selected futures on forage, wildlife, trout, and water in the southern United States

Resource and year	Baseline	Reduced forest land	Reduced timber growth
Forage—forest (1000 tons)			
1985	16,961	16,961	16,403
2000	19,945	19,371	20,922
2010	20,021	19,436	21,930
2020	19,623	19,017	22,279
2030	19,117	18,392	22,226
Forage—Pasture/range (1000 tons)			
1985	109,265	108,701	109,265
2000	103,230	103,551	103,230
2010	99,454	100,214	99,455
2020	96,239	97,439	96,239
2030	93,816	95,424	93,816
White-tailed deer (number/sq mile)			
1985	17.3	17.3	17.3
2000	16.5	16.8	16.4
2010	16.0	16.3	15.7
2020	14.7	15.1	14.6
2030	14.2	14.5	14.2
Turkey			
1985	5.9	5.9	5.9
2000	5.4	5.4	5.4
2010	5.2	5.2	5.2
2020	5.5	5.3	5.5
2030	5.6	5.5	5.7
Red-cockaded woodpecker			
1985	170	169	167
2000	95	95	89
2010	87	85	87
2020	84	83	83
2030	83	80	81
Trout			
1985	171	170	171
2000	162	172	162
2010	131	153	130
2020	120	143	121
2030	119	143	121
Water yield (inches)			
1985	15.7	15.7	15.7
2000	16.1	16.2	16.1
2010	16.3	16.5	16.4
2020	16.3	16.5	16.4
2030	16.3	16.7	16.5

increases in the cropland area result in a diminishing of the habitat and deer densities decline. The net result is a slight increase in South-wide deer density. Turkey density trends are similar to the baseline. The number of counties supporting active red-cockaded woodpecker colonies declines slightly compared to the baseline—a response to additional loss of area in the natural pine type.

In the second scenario, the reduction of timber growth results in major impacts in the timber harvest and related industries in the South. By 2030, softwood inventories on private land are 35% below the base scenario projection (USDA 1988). Forage production on forest land is 16% higher in 2030 than in the baseline. The reduced tree growth translates into a more open canopy and results in improved conditions for forage production. Wildlife density and occurrence projections show only slight variation from the baseline. Slight changes in water yield with land use held constant result from changes in stand age.

Discussion

The objective of this analysis was to provide results from which planners and policy makers could identify multiple resource responses resulting from changes in land-use and timber-management activities. Our critique of this approach will focus on (1) the multiresource framework and method of integration, (2) land and resource data supporting the resource models, and (3) individual model development and testing. Finally, we include recommendations for future regional multiresource modeling.

Multiresource Framework and Integration

The integration of resource projections is possible in this study because timber-management and land-area changes could be translated into the commonly defined land classification (Table 1). For this study area, land inventories existed that could be amalgamated using an iterative proportional fitting procedure to produce a complete land base description with a minimal difference (<1%) between amalgamated estimates and the original inventories at the state level. The use of commonly defined timber and land descriptors frees the integrated analysis from the constraints of a common geographic unit, i.e., all models operating at the state level. Our method of integrating resource inventories preserved the ability to describe the study area at the coarsest geographic level (subregion) or at the finest level of inventory detail (county) (Figure 1). Subsequent aggregation of analysis results to a common geographic area provided a multiresource projection tool that was less constraining than forcing all resources to be modeled within the same unit of land. Forage production can be projected at the timber-stand level, and wildlife densities at the county level.

The ability to construct a common and significant set of land base descriptors was constrained by the extant policy models. Land classification for the multiresource framework was influenced by economic rather than ecological objectives. The timber-management types of natural and planted pine represented managerial generalizations about the many softwood types in the South. An empirical error in estimating timber volume for natural pine rather than specifically for slash pine or longleaf pine types causes few problems in the regional estimation of timber volume. However, differences in canopy closure rates among pine types (Wolters 1982) and varying woodpecker preferences for pine species (USDI 1985) affect forage production and woodpecker occurrence, respectively. Thus, constraints in the set of common descriptors limit the precision of the production estimate within each resource model.

Feedbacks from resource management for forage, wildlife, trout, and water are incorporated indirectly into the modeling framework. Because these resource models were based on a cross-sectional data set, the influence of historical management practices are inherent in the data. Thus, while current wildlife populations reflect past management practices, no parameters can be related directly to the impact of wildlife management on wildlife. While this shortcoming is most often a criticism of statistical models, the mathematical framework of a simulation model with explicit feedbacks presumes a management style and will also suffer under shifts in management practices. Along these lines, the inability to examine the full impact of environmental change was evident in the reduced tree growth scenario. The many possible environmental effects that could cause a reduction in tree growth were not implemented in the timber model, rather only the rate of growth was altered. Thus, the system's perception of reduced tree growth was in the land-area changes that resulted from increased pressure on timber harvesting, not an ecological change. While all resource models project this harvesting influence, there are many ways in which the impact of a reduction in tree growth could occur, and presumably, some of these ways could influence the production of other resources. For example, one agent of change might be increased drought. This change and other possible change agents could have additional impacts on the timber resource, as well as affecting the understory vegetation and wildlife.

Land and Resource Data

Bias in inventory sampling, either the land base or the resource, will confound the statistical models developed from these inventories. The FS inventory focuses on commercial forest land, that is, land capable of producing 20 cubic feet of industrial wood per acre per year. Forage production relationships developed from inventories on these lands describe forage production on sites managed for timber. Forage production from noncommercial sites, admittedly a small part of the southern forest land base, is not included in the overstory–understory analyses. A similar bias occurs in the trout model because the streams sampled were selected based on high probability of trout occurrence. Consequently, there were few data for watersheds where trout abundance was low, and the model will reflect only habitat relationships in watersheds where trout are likely to occur.

Model Development

Ecological factors that were known to be significant in resource production, that could be identified in the inventory data, and that were projected by the land area and timber models were incorporated directly into each resource model. Limitations associated with inventory data and the variables projected in the extant policy models resulted in less than all of the variability in the resource data explained by the resource models (Flather 1988, Flather and others 1989, Flebbe and others 1988, Joyce 1988). A further set of management variables was indirectly incorporated into the resource models. Ownership management characteristics, such as rotation length and regeneration with improved genetic stock, were incorporated directly into the growth functions developed for each ownership in the timber model but indirectly in the other resource models. As the forage model works within the timber-management classification, the effect of ownership is indirectly incorporated when timber volume estimates for each ownership are used to estimate the associated forage production. Within the wildlife, trout, and water models, the distribution of acres across timber type–age classes within a county is often an indication of harvesting policy that differs by ownership. Thus, the distribution of the red-cockaded woodpecker is highly correlated with ownerships where rotation lengths were longer.

Ecological factors known to be significant in resource production, such as the spatial patterns of land use and cover, were not available for consideration. Thus, part of the variability in the wildlife relationships is the result of counties with similar land-use composition having different spatial distributions. In addition, spatial patterns change over time, as farms are broken up into smaller enterprises or merged into larger corporate operations. The current spatial patterns were taken as the starting point to distribute the projected changes across the landscape. Thus the wildlife, water, and trout models assume that the patterns of land use (size, shape, and distribution) do not change dramatically over the projection period or at least do not change in a manner that affects these resources. We are examining the possibility that this assumption may have introduced a bias in future land-cover/use patterns.

The data and modeling assumptions that underlie the modeling of timber growth are critical to multiresource interactions analyses. Growth and yield functions are estimated from historical inventory data, primarily from even-aged sites. Much of the South is in mixed-aged stands where the resource relationships will be different than in even-aged stands. In addition, harvesting strategies that move through the age classes from oldest first until the harvest demand is met will produce a very different distribution of age classes within a region than if acres are harvested from all age classes at specified rates until the harvest demand is met. The significant drop in red-cockaded woodpecker is related to the large reduction of old-age sites within pine types.

Model Testing

Validation has been defined as any process that examines the correspondence between the model and the system under study (Van Horn 1971, Mihram 1972). Validation requires that information on system behavior be available independent of information used to construct the model. However, strict adherence to this requirement is not always possible or desirable, as much can be learned about system and model behavior with a more eclectic approach to evaluating model performance. Other approaches include sensitivity analysis (Gardner and others 1981), error analysis (Mowrer 1988), reliability analysis (Warwick and Cale 1988), resampling estimates of model error (Efron 1982), and evaluation of model behavior against expert review (Turing 1950, Van Horn 1969). Despite this variation in approach, all share a common goal of assessing the source and magnitude of error.

We define two broad classes of error. First are errors associated with projecting future system states, which includes propagation of error through time and from one model to another, or instability in empirical relationships over time. Second are errors associated with the model development process, including representativeness, precision, and accuracy of input data and correct model specification.

The difficulty with validating projection errors is that the system under study operates in the future. Historical data could be used; however, land and resource data of sufficient spatial and temporal extent to test regional models is exceedingly rare. Consequently, evaluating projection error was accomplished qualitatively by comparing model and expert-generated projections for forage, wildlife, and trout production, given a common set of land-use and land-cover trends. In all cases, model behavior was consistent with expert-generated estimates of future trends in resource production. As expert opinion was used in developing the water model, there was no basis for a similar comparison.

Techniques for assessing errors associated with model development are more varied and tend, in many cases, to be founded on traditional statistical theory. In the case of the forage model, independent data from similar ecological systems were compared to model predictions for individual timber stands. Model forage estimates fell within the error bounds of previously developed models with one exception. Forage produced on young forest stands was underestimated. This was the result of using ten-year timber age classes and the large variability in forage production in young stands. For wildlife and trout, the paucity of data prevented examination of error with a complete set of independent observations. A cross-validation technique that bases model error estimates on observations that are sequentially "held out" was used to generate a less biased estimate of classification accuracy (Efron and Gong 1983). Cross-validation estimates of classification accuracy were 60%, 67%, and 76% for deer, turkey, and red-cockaded woodpecker—a pattern suggesting that empirically generated habitat relationships are more stable, when compared to the resubstitution estimates of error reported earlier, for specialists (red-cockaded woodpecker) than generalists (deer). The cross-validation estimate of trout model accuracy (47%) raises a caution as to the generality of this model.

Because empirical data at the regional level were lacking, evaluation of errors associated with development of the water model was not possible. This, combined with the inability to examine projection behavior with expert review, means that the water model has not received any form of model validation. Consequently, the results reported here, and any future applications, must be interpreted with caution.

Future Multiresource Modeling

The modeling framework for a resource management problem must integrate the underlying processes of the environmental system and the effects of management. The processes that are chosen for integration reflect their significance to the management problem and should at least consider the following set of factors:

1. Nature of the management question. Points to consider include management/analysis objectives, policy level (site, state, region), and the frame of reference (extant policy models).
2. Ability to quantify the underlying processes. Quantification is influenced by the existence of accepted theoretical constructs upon which to base model specification and data availability for parameter estimation or development of empirical models.

The most basic recommendation is to make all resource areas equally important in the specification of information for an accurate description of the environmental system under study. We have been able to demonstrate that forage production, wildlife and trout abundance, and water yield can be linked to regional land-use and timber-management models. However, this linkage was opportunistic—timber and land-use models essentially constrained the suite of variables that could be considered in the forage, trout, water, and wildlife analyses—and unidirectional—the impact of land area and timber on the other resources. A significant improvement in our approach would involve the explicit specification of variables that are most important to all resources and constructing a projection tool that would address all such variables. This approach could incorporate size, shape, and distribution of land-use and -cover types or more detailed information on forest types.

A second recommendation concerns feedback concepts. The current multiple resource framework only addresses the impacts of land use and timber management on other resources. Modification of the growth and yield functions based on changes in other resource production levels would initiate an evolution toward a truly interactive analysis and improve the capability to represent the complexity of multiple resource systems.

A related recommendation involves expansion of economic factors affecting land management activities to include the economics of managing for forage, water, trout, or wildlife. The economic value of these resources affects the transition of land to other uses and how timber is managed. Currently, the value of these other resources is not considered when analyzing how private landowners allocate their land resources to various uses and intensities of timber management.

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